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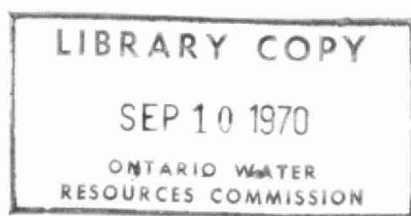
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SOME NOTES ON
SMALL CONFINED HARBOUR
DILUTION CHARACTERISTICS

WHEATLEY, 1968



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135 St. Clair Ave. West,
Toronto 195, Ontario.

M. D. Palmer

SOME NOTES ON SMALL CONFINED HARBOUR
DILUTION CHARACTERISTICS

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ABSTRACT

Water movement measurements taken with respect to time in Wheatley Harbour in June indicate that movements are periodic throughout the harbour and correspond to wind seiche activity. The dispersion coefficients are reasonably constant throughout the harbour and less than general surface characteristics farther offshore by approximately three orders of magnitude.

SOME NOTES ON SMALL CONFINED HARBOUR DILUTION CHARACTERISTICS

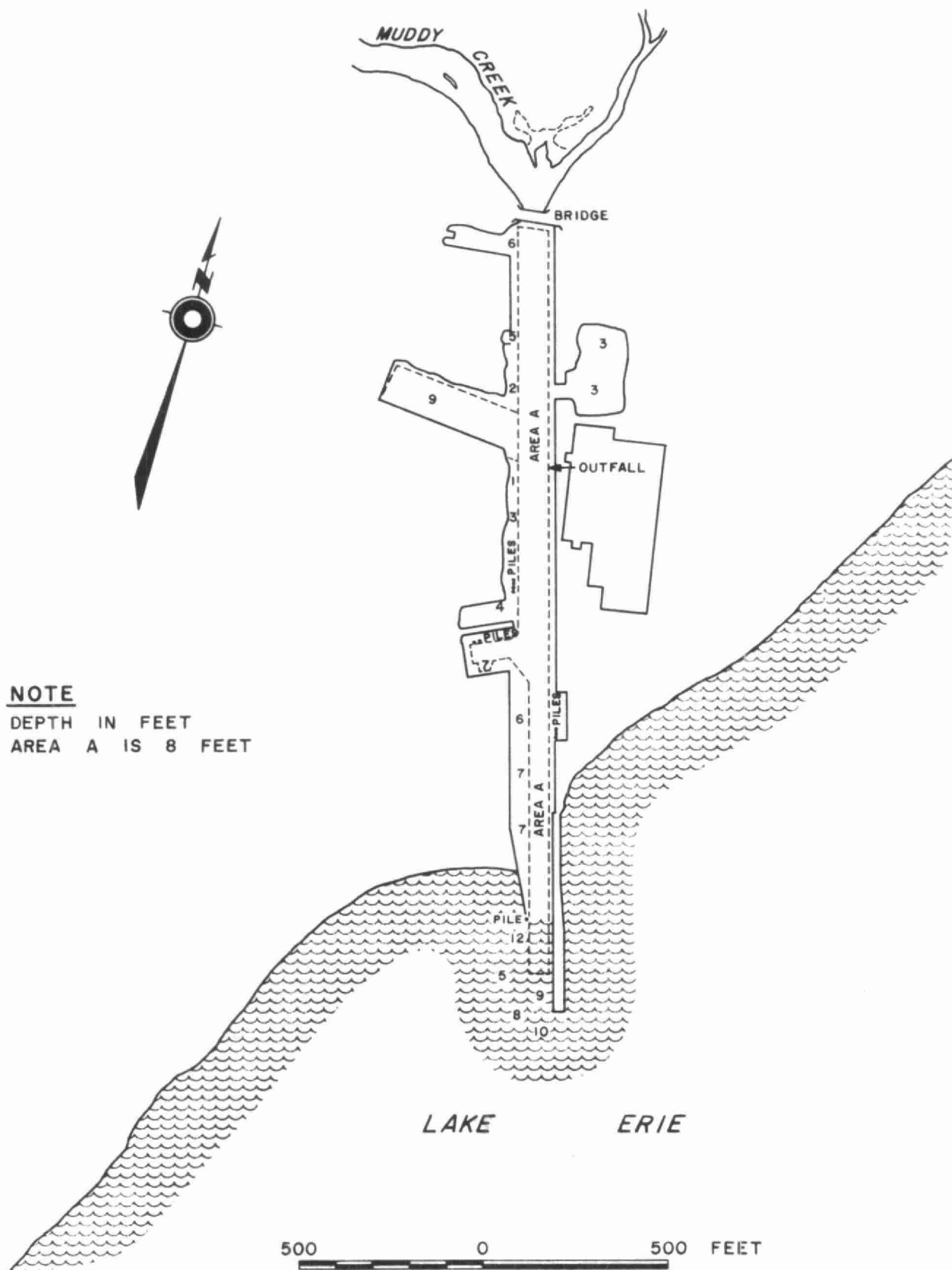
WHEATLEY, 1968

INTRODUCTION

Many small confined harbours on the Great Lakes are at the outlets of small creeks on the lakeshore. The flushing action provided from these small creeks is periodic and often small in volume compared to the harbour water volume. A study was undertaken at Wheatley Harbour (Fig. 1) in 1968 after a large rainstorm in the early summer to determine dilution and flushing action in the harbour. Wheatley Harbour was selected as a typical example of a harbour with a convenient channel-like cross-section and a bridge located at the northern end of the harbour where Muddy Creek enters the harbour. Velocity as a function of time was measured at several depths under the bridge and dye concentrations as a function of time were measured in the confines of the harbour near the bridge (inner harbour) and the area near the breakwater (outer harbour).

FIG. 1

WHEATLEY HARBOUR

APPROXIMATELY $42^{\circ} 03' 13''$ N., $82^{\circ} 28' 06''$ W.

WATER MOVEMENT

A Gurley current meter study carried out in the middle of the channel below the bridge at the northern end of the harbour at the surface, mid-depth and bottom revealed the flow to be pulsating (see Fig. 2). This study took place a few days after the summer season's most intensive rainfall (Table 1) when the flow in Muddy Creek would be significant although not as large as spring runoff conditions.

TABLE 1
RAINFALL
(inches)
Field Work on 30 June

June	24	25	26	27	28
Leamington	0.08	2.80	0.30	0.50	0.09

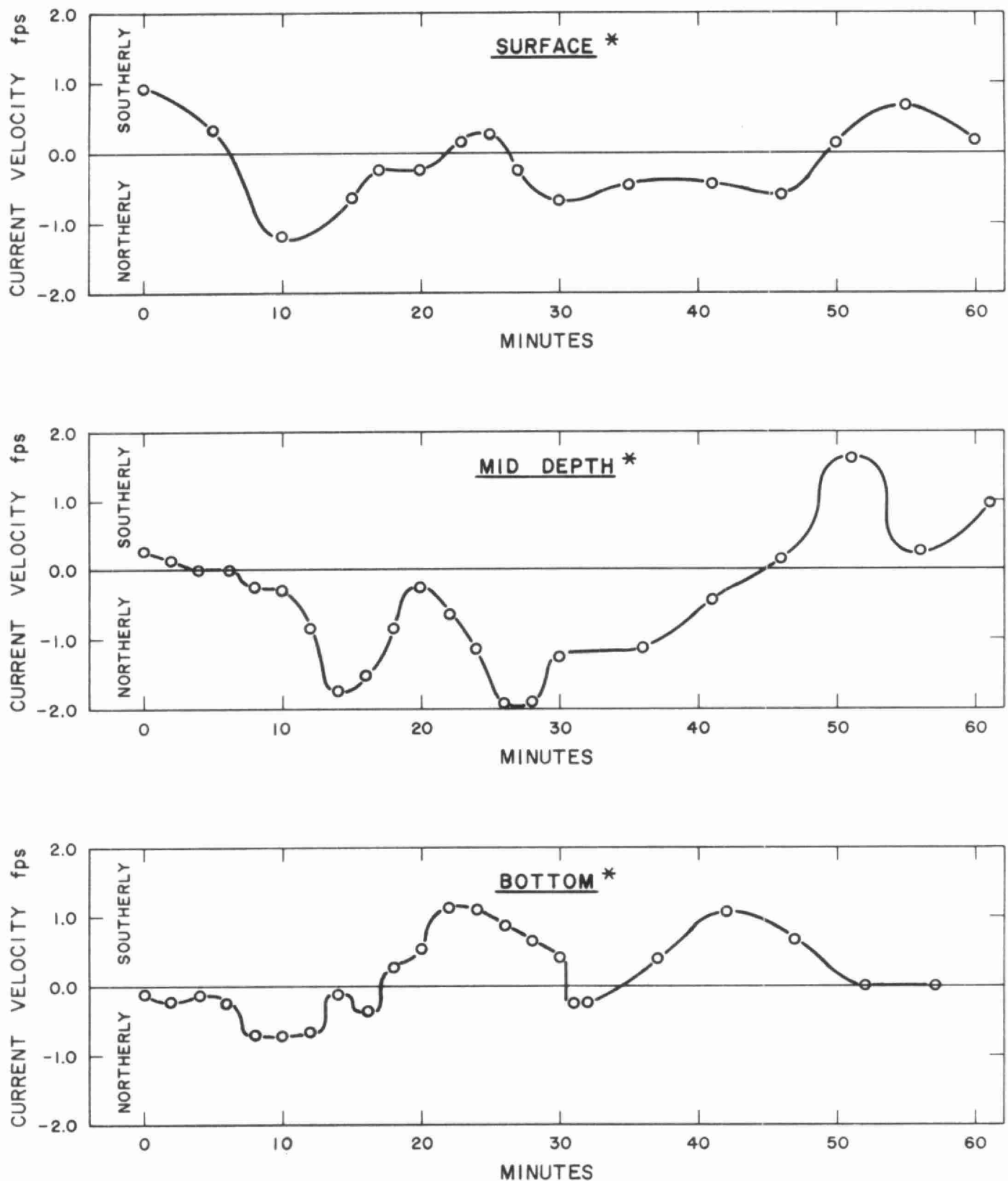
Pulsating flows in confined shore areas are normally indicative of wind-water interaction. Consequently, the wind driven currents appear to be the most predominant feature of water movements in the harbour.

The winds during this part of the study were 12 knots at 210° with the effective component acting along the channel of $12 \cos 40^{\circ}$ or 9.3 fps. According to Proudman (1953), the period for a confined basin may be represented by Merian's formula:

$$T = \frac{4L}{\sqrt{gH}} \quad \dots (1)$$

CURRENTS IN WHEATLEY HARBOUR AT BRIDGE

JUNE 30, 1968



* NOTE: THREE PROFILES ARE NOT
CONCURRENT IN TIME i.e. RANDOM
SAMPLING WITH ONE METER.

where T = period in seconds,
 L = length of area in feet,
 g = acceleration due to gravity
 ft/sec^2
 H = channel depth in feet.

For Wheatley Harbour, this becomes:

$$T = \frac{4 \times 2140}{\sqrt{32.2 \times 8}}$$

$$T = 8 \text{ minutes.}$$

Figure 2 indicates measured period of approximately 20 minutes. This discrepancy could be due to the wave reflection from the various side channels (see Fig. 1), the reservoir effect of Muddy Creek acting as a damper on the channel period or the depth of the channel not uniformly eight feet. If the side channels are added to the channel length and the average depth assumed six feet, Merian's formula becomes:

$$T = \frac{4 \times 4200}{\sqrt{32.2 \times 6}}$$

$$T = 20 \text{ minutes.}$$

Further, if one takes into account the dampening due to friction (Defant, 1961, p. 157)

$$\xi = \frac{\pi}{L} = \frac{3.14}{4200} = 7 \times 10^{-4} \quad \dots (2)$$

$$\delta = \frac{\nu^2}{g \xi^2 H^5} \quad \dots (3)$$

where ν = kinematic viscosity

$$\delta = \frac{(1.3 \times 10^{-5})^2}{32.2 (7 \times 10^{-4})^2 6^5}$$

$$\delta = 0.13 \times 10^{-8}$$

from Table 20 (Defant, 1961, p. 159)

$$T = 1.003 \times 20$$

$$T = 20 \text{ minutes}$$

it is found that friction has a negligible effect on lengthening the period.

The surface velocities resulting from winds in small enclosed channels can be computed after Keulegan (1951).

$$U_s = 0.033 \times \text{wind velocity} \quad \dots (4)$$

$$\text{if } Re = U_s H / \nu > 1000$$

$$\text{where } U_s = \text{surface velocity in fps}$$

$$U_s = 0.033 \times 9.3 = 0.31 \text{ fps}$$

$$\text{and } Re = \frac{0.31 \times 8}{1.5 \times 10^{-5}} = 1.6 \times 10^5 > 1000$$

This compares favourably with the measured surface maximum of 1.0 fps when one considers that measurements under the bridge were taken at a point where the harbour cross-section is reduced by a factor of three. Therefore, maximum theoretical velocity = $3 \times 0.31 = 0.93$ fps.

It is apparent that the main water movement in the harbour during the study is wind driven. This means that any discharge into the harbour will remain in the confines of the harbour for a long time and simply be thoroughly mixed by the pulsating currents. The only significant removal of material from the channel will be by diffusion at the harbour entrance.

DISPERSION CHARACTERISTICS

The dispersion characteristics of both the inner and outer harbour were measured by introducing a fluorescent dye, Rhodamine WT to the surface as a sudden input. As the harbour is shallow, surface dispersion characteristics were felt to be the best measure of dispersion. Approximately 4 oz of a 20 per cent concentration dye was released on the surface and the time recorded. Subsequently, the dye plume was sampled to measure the maximum concentration occurring at later times (Noble 1961). The concentrations were determined with a fluorometer. The dilution curves obtained are presented in Figures 3 and 4 for the inner and outer harbours respectively.

$$\log \frac{C(t)}{C_0} = -At \quad \dots (5)$$

where $C(t)$ = concentration at time "t" in ppb

C_0 = concentration at time zero in ppb

FIG. 3
INNER HARBOUR DILUTION CURVE

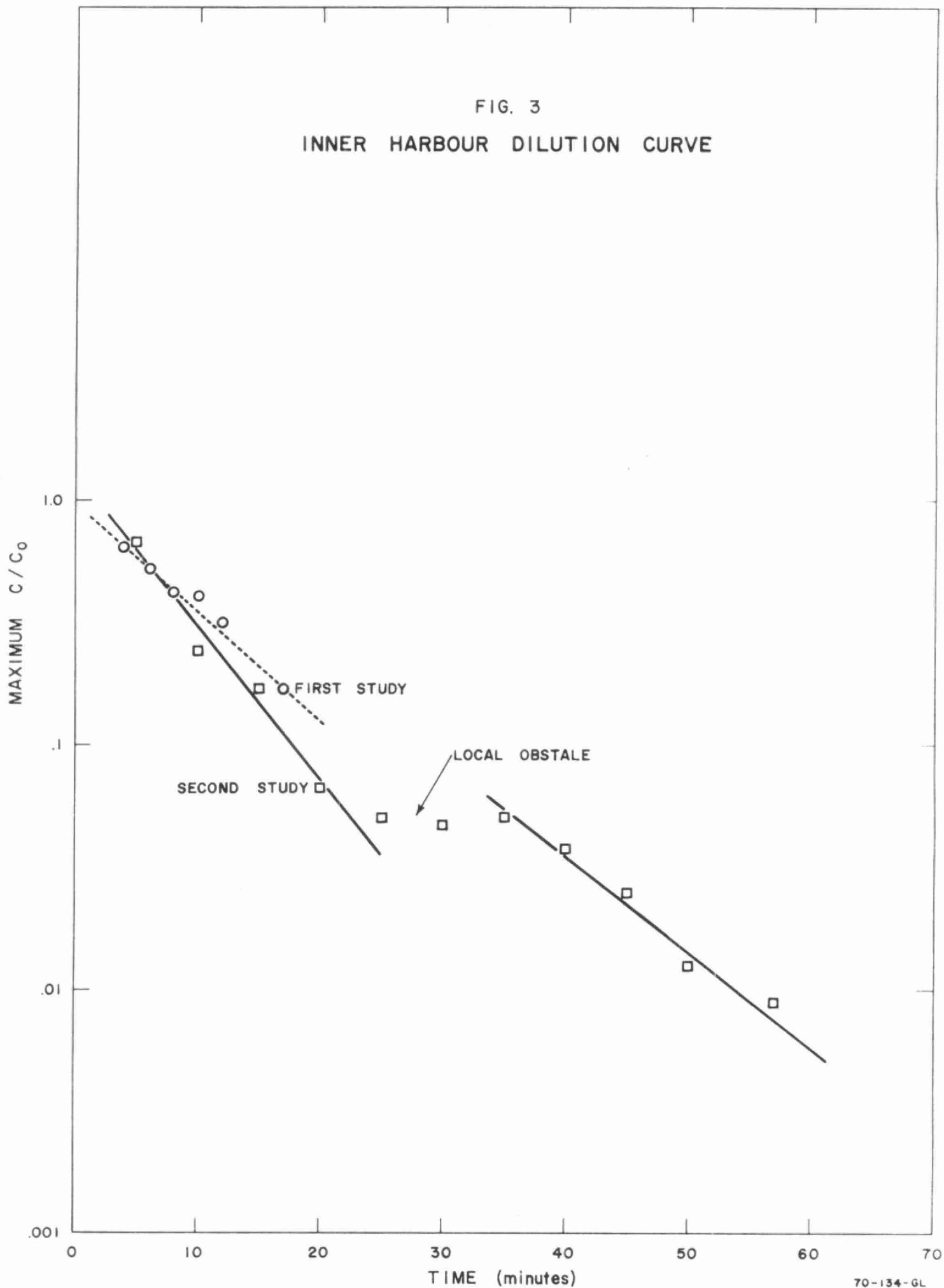
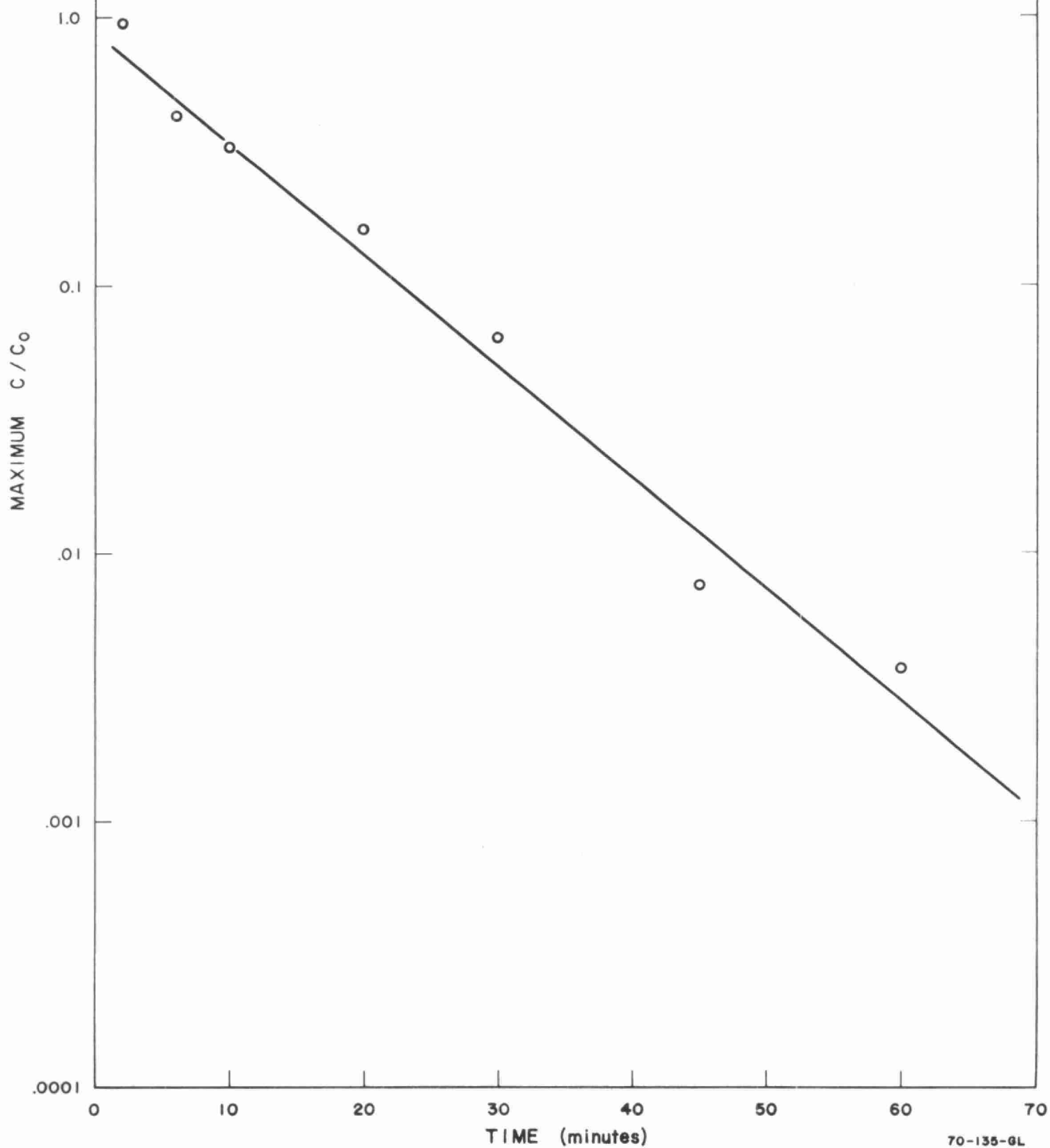


FIG. 4
OUTER HARBOUR DILUTION CURVE



$$A = \text{slope}$$

$$t = \text{time in minutes}$$

$$\text{and } \frac{C(t)}{C_0} = e^{-t/\tau} \quad \dots (6)$$

For the inner harbour:

$$A = \frac{1.067}{53} = 0.0202 \text{ (minutes)}^{-1}$$

$$\tau = 21.5 \text{ minutes}$$

For the outer harbour:

$$A = \frac{1.042}{49} = 0.0214 \text{ (minutes)}^{-1}$$

$$\tau = 20.3 \text{ minutes}$$

These values for τ fall within the limits found by Noble (1961) $8.6 < \tau < 29.8$ minutes with the higher values characteristic of slow dispersion. Therefore, the dispersion in the outer harbour is greater than the inner harbour.

Now the classical diffusion equation:

$$\nabla^2 C = \frac{1}{D} \frac{dC}{dt} \quad \dots (7)$$

has a solution for specific initial and boundary conditions and applying Green's function (Noble, 1961)

$$\frac{C(t)}{C_0} = 1 - \exp(-\tau_D/t) \quad \dots (8)$$

$$\text{where } \tau_D = \frac{b^2}{4D}$$

b = radius of initial dye patch

= 1 foot

D = diffusion coefficient $\text{ft}^2/\text{min.}$

Following the method of Noble (1961) by equating the experimental dilution curve with the linear approximation for the classical diffusion equation:

Inner Harbour D = $12.7 \text{ ft}^2/\text{min.}$

Outer Harbour D = $13.4 \text{ ft}^2/\text{min.}$

Noble (1961) points out that the classical diffusion constant does not match the experimental dilution curves. However, the classical diffusion equation or the molecular diffusion equation represents the dispersion of a quantity with time and space under a driving force of the concentration gradient tending to produce a homogeneous mixture. To be applicable to an area "D" it must include mixing effects resulting from water velocities and turbulence. Consequently, it has been found to vary from $4.55 \text{ ft}^2/\text{min.}$ for regions of 660 yards to $6.4 \times 10^6 \text{ ft}^2/\text{min.}$ for regions of miles (Noble, 1961). An extensive discussion of relationship between diffusion and the mean velocities and turbulence characteristics can be found in Chapter 5, Hinze (1959). Fischer (1967) successfully approached the dispersion characteristics of natural streams by measuring mean velocities in two dimensions. However, it does not seem appropriate to apply a stream technique

when the velocities are periodic with little outflow from the harbour.

The dispersion coefficients are significantly smaller than those determined by Okubo (1967) who determined $3.5 \times 10^3 > D > 2.6 \times 10^3$ $\text{ft}^2/\text{min.}$ farther offshore in Lake Erie. Okubo employed the relationship (equation (9)) for long term dispersion coefficient (Hinze 1959, p. 333)

$$D = \overline{y^2} (t)/2t \quad \dots (9)$$

where $\overline{y^2} =$ variance of particle spread ft^2

If these assumptions are applied to Wheatley Harbour assuming the dye plume concentration maintains a normal curve distribution (Hinze 1959, p. 290) and continuity in two dimensions for approximately two periods (40 minutes), the following dispersion coefficients are determined:

$$\text{Inner Harbour} \quad D \approx 4.2 \text{ ft}^2/\text{min.}$$

$$\text{Outer Harbour} \quad D \approx 9.5 \text{ ft}^2/\text{min.}$$

It is observed that equation (9) predicts the dye measured dispersion coefficients within an order of magnitude. However, the dispersion coefficients are generally larger in the harbour due to the pulsating flow but less than general surface lake coefficients well offshore by a factor of 1,000.

CONCLUSIONS

Field measurements of water movement in the confines of Wheatley Harbour indicate the velocities are time variant throughout its depth corresponding to wind driven seiches. The flushing effect of Muddy Creek during the study was negligible. Dye dispersion measurements indicate that the dispersion characteristics are reasonably constant throughout the harbour with only slightly better characteristics at the harbour entrance. The harbour dispersion coefficients are significantly less than lake surface values offshore by approximately three orders of magnitude.

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